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AC MOTORS SUPPLIED FROM STATIC CONVERTER

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I. INTRODUCTION

With the development of semiconductor power converters, it has become easy to obtain variable frequency power supplies and AC motors can be employed as variable speed power sources. These variable speed motors have the same control characteristics as the DC motors which are hitherto widely used as variable speed power sources and since there are no parts such as brushes or commutators which require maintenance, they are highly evaluated and are expected to expand gradually in the future.

However, differing from the normal sinusoidal AC power supplies, there is considerable distortion in the voltage and current obtained from the converter. The harmonic content is high and there must be thorough investigations of the effects of this on the motor so that they can withstand it.

For the converter on the power supply side, it is desirable that the system have as few harmonics generating as possible and efforts are continuing in this respect.

This article describes the effects of the current harmonics on the electrical characteristics and generated torque of the motor, the concepts of the commutating reactance which has great influence on the power supply converter as the motor impedance, and also operation limits. The points which should be considered concerning various types of motors are also pointed out.

II. WAVEFORM PROBLEMS OF VOLTAGE AND CURRENT

1. Waveforms

There are two main types of variable speed AC motors: those using synchronous motors and those with induction motors. Then two types of thyristor converters can also be considered for driving these motors.

One acts as a current source and supplies square wave current to the motor. The other acts as a voltage source and supplies square wave voltage. Since the former is suitable for the multiple quadrant operation of single motors, they are used for commutatorless motors (synchronous type motors) and large capacity squirrel cage indction motors. The latter are used as variable voltage and variable frequency power supplies for group control of squirrel cage motors, etc.

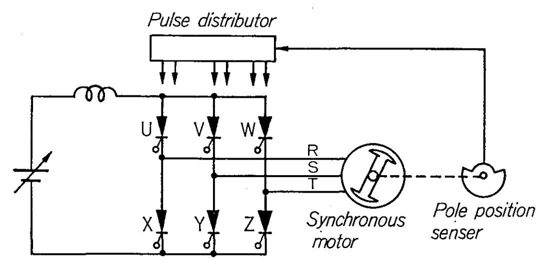


Fig. 1 Principle circuit of commutatorless motor

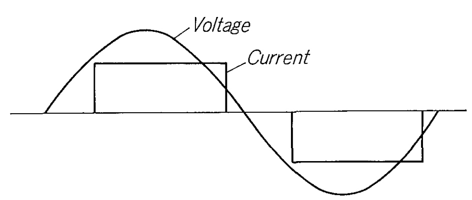


Fig. 2 Waveform of voltage and current

(1) Waveforms of current type

Fig. 1 shows the principle circuit of the DC commutatorless thyristor motor. *Fig. 2* shows the waveforms of the current flowing in each phase of the motors. When the overlapping angle u is zero with 6 pulses control, the current conducting during 120° angle. Generally, the magnitude of the nth harmonic I_n is as shown in equation (1) to a fundamental wave current I_1 by means of Fourier analysis:

$$I_n = \frac{K_n}{n} I_1 = \frac{K_n}{kp \pm 1} I_1 (k=1,\ 2,\ 3......) \quad ....(1)$$

p: number of commutating pulses
K_n: function of overlapping angle and control angle

The number of harmonics which are generated becomes $n=kp\pm1$. In *Fig. 1* where $p=6$, $n=5$, 7, 11, 13,...... The upper part of *Table 1.* shows the harmonic content when the overlapping angle is

Table 1 **Content of harmonics current**

case	n	5	7	11	13
1	$I_n(\%)$	20	14.3	9.1	7.7
2	$I_n(\%)$	14	7.2	2	1.5

1 : When $K_n=1$, 2 : When commutator reactance drop is 12%.

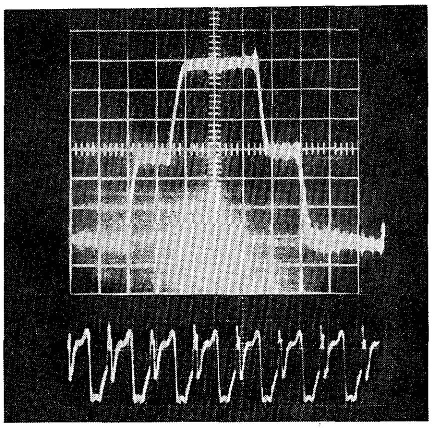


Fig. 3 Oscillogram of armature current and damper current

$u=0$ as in *Fig. 2*.

Generally, the overlapping angle exists due to the commutating reactance X_u and as an example, when IX_u is 12%, the harmonic content of I_n becomes small as shown in the bottom part of *Table 1*. *Fig. 3* shows an oscillogram of the actual current flowing to the motor.

(2) Waveform of voltage type

The voltage waveform applied to the motor in the case of a voltage type inverter with 6 pulse control is a square wave voltage as shown in the oscillogram in *Fig. 4*. The following equation shows the results of Fourier expansion:

$$v=\frac{2\sqrt{3}}{\pi}E\left\{\sin\omega t-\frac{1}{5}\sin 5\,\omega t\right.$$
$$\left.-\frac{1}{7}\sin 7\,\omega t+\frac{1}{11}\sin 11\,\omega t+\ldots\ldots\right\} \quad \ldots\ldots\ldots\ldots\ldots(2)$$

where E: square wave voltage peak value
ω: angular velocity of fundamental wave (rad/s)

In this case the 5th and 7th harmonic components are large and the current corresponding to this flows as shown in *Fig. 4*.

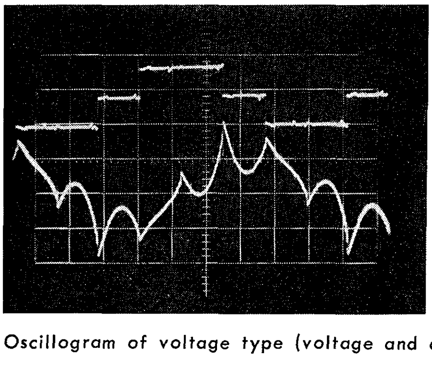


Fig 4. Oscillogram of voltage type (voltage and current)

The harmonic components of the current in this case are larger than in the case of the current type, so that these should be considered at the time of motor design or the harmonic components shall be reduced by using a multiple inverter or a pulse width modulation type inverter.

2. Effect on Electrical Characteristics by Current Waveform

(1) Effect on damper winding (or squirrel cage winding)[(1)]

When the square wave curret shown in equation (1) flows in the 3-phase stator winding of the motor, the total magnetomotive force shown in equation (3) produces:

$$\Sigma M=A_0K_{W1}\left\{I_1\sin\left(\omega t-\frac{\pi}{\tau}x\right)\right.$$
$$+I_5\sin\left(5\,\omega t+\frac{\pi}{\tau}x\right)+I_7\sin\left(7\,\omega t-\frac{\pi}{\tau}x\right)$$
$$\left.+I_{11}\sin\left(11\,\omega t+\frac{\pi}{\tau}\right)+\ldots\ldots\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where A_0 : constant
K_{W1} : winding coefficient for fundamental wave
τ : pole pitch
x : distance on stator circumferetial direction

The first term of the equation is the rotating field of the fundamental wave. The wave length by the magnetomotive force formed from I_5 in the second term of the equation is the same as that of the fundamental wave and since this is a "time harmonic magnetomotive force" which rotates in the opposite direction to the rotational field of the fundamental wave and at a speed five times faster, a six-fold harmonic voltage is induced in the rotor circuit. The magnetomotive force due to I_7 is rotating in the same direction as the rotor at a speed 7 times faster and also induces a six-fold harmonic voltage in the rotor circuit.

In other words, the 6th harmonic voltage due to I_5 and I_7, the 12th harmonic voltage due to I_{11} and I_{13} and the 18th harmonic voltage due to I_{17} and I_{19} are induced in the rotor circuit.

If there is no circuit such as a damper winding (or squirrel cage winding) provided in the rotor circuit to absorb and eliminate this time harmonic magnetomotive force mentioned above, these fields will not only effect an increase in the leakage reactance for stator windings but there will also be big distortions in the current waveform and the good commutation effect will be lost. Therefore, stable operation will not be achieved. When there is a damper winding, the six-fold speed rotating field in the rotor due to I_5 and I_7 is eliminated by means of a current in the damper winding corresponding to the operating characteristics at a slip of $S=6$ with normal slip torque chracteristics. However, the part of the field corresponding to the damper impedance voltage drop is not eliminated and remains in air gap.

If this remaining field is large, the commutating reactance and the overlapping angle u will increase as described later and the stable motor operating zone will become narrow so that reliable operation can not be achieved. Therefore, it is necessary in the thyristor motor to provide a damper winding with low leakage reactance and low resistance and sufficiently high absorption characteristics.

It is convenient to express the loss of I^2R due to the current in the damper winding by the equivalent reverse phase current I_{2eq}. Although there is a second harmonic current flowing in the rotor circuit for the normal reverse phase current, I_{2eq} is obtained if the loss due to I_{2eq} is made equal to the loss due to the harmonic currents for $n=6$, 12, 18……

$$I_{2ep}=\sqrt{\sum_{\nu}\left(\sqrt[4]{\frac{\nu}{2}}\cdot I_{\nu}\right)^2} \quad \text{.................(4)}$$

where ν : order of harmonics

As an example, when calculation are made for only $I_5=14\%$ and $I_7=7.2\%$ in *Table 1*, I_{2eq} is approximately 28% at $\nu=6$. In the usual synchronous machine, the permissible reverse phase current according to IEC Recomendation Pub. 34-1 is 12% and the damper current at the commutation period described later must be considered. Therefore, in the actual motor design, it is essential to select the type of machine and also be sure that the damper or squirrel cage winding be designed with a sufficiently high thermal capacity.

(2) Effect on stator windings

Because $R_n/R_0=(1+Kn^2)$ arises between the resistance R_n in respect to the nth harmonic wave and the DC resistance R_0 of the stator winding, the loss P_C within the winding produced by harmonic current becomes as in equation (5).

$$P_C=\sum_{1}^{\infty}I_n^2R_0(1+Kn^2) \quad \text{.................(5)}$$

In normal motors, there is only a $I_1^2R_1$ loss and the increase of loss in the case of converter power supply is as follows:

$$P_C-I_1^2R_1=\sum_{5}^{\infty}I_nR_0(1+Kn^2)$$

K is related to the coil strand thickness d and when the current density is constant, it becomes $K\propto d^2$. Therefore, one effective method to reduce the loss is to make the strand thin. When round wires are used in small motors, the increase of the loss is comparatively small but in large capacity motors, considerable care is necessary when square strand are used in the coils.

It is also necessary to consider the increase in iron loss (about 10～20%) because of the harmonics.

3. Effects on Torque by Current Waveform

Investigations were performed to determine the effect on the torque when the square wave current described previously is flowing in the armature windings. For detailed analysis, the d–q axes conversion[2] and configuration shift methods[3] have been used with analyses to determine the solution about one of the repeatable intervals. However, here a more qualitative approach will be used.

1) Synchronous motors

The field B_R induced from the field coil of the rotating field is as shown in equation (6) when considering only the fundamental wave as viewed from the rotor side:

$$B_R(x)=B_{R1}\cdot\sin\frac{\pi}{\tau}x \quad \text{.................(6)}$$

where B_{R1} : peak value flux density

x : distance on rotor circumferential direction

Of the fields interlinking in the rotor circuit because of the square wave current flowing in the stator winding, the harmonic components other than the fundamental wave component are almost completely eliminated by the damper windings but the leakage reactance component remains as a gap field. When the fundamental wave component is taken as $B_{S1}\cdot\sin\left(\frac{\pi}{\tau}x+\delta\right)$ where δ is the internal angle, the residual 5th component becomes $B_{S5r}\cdot\sin\left(6\omega t+\frac{\pi}{\tau}x\right)$ and the residual 7th component becomes $B_{S7r}\cdot\sin\left(6\omega t-\frac{\pi}{\tau}x\right)$. Therefore the torque is obtained by multiplying these fields and the field in equation (6).

When the fundamental wave torque and the torques due to the 5th, 7th and other components are expressed as τ_1, τ_5, τ_7,…… equation (7) to (9) are obtained:

$$\tau_1(x)=B_{R1}\cdot B_{S1}\cdot\frac{1}{\sqrt{2}}\sqrt{1-\cos\left(\frac{2\pi}{\tau}x\right)}\sin(\delta+\varphi_0) \quad \text{.................(7)}$$

$$\tau_5(x)=B_{R1}\cdot B_{S5r}\cdot\frac{1}{\sqrt{2}}\sqrt{1-\cos\left(\frac{2\pi}{\tau}x\right)}\sin(6\omega t+\varphi_0) \quad \text{.................(8)}$$

$$\tau_7(x)=B_{R1}\cdot B_{S7r}\cdot\frac{1}{\sqrt{2}}\sqrt{1-\cos\left(\frac{2\pi}{\tau}x\right)}\sin(6\omega t-\varphi_0) \quad \text{.................(9)}$$

$$\text{where}\quad \varphi_0=\tan^{-1}\left\{\frac{1-\cos\left(\frac{2\pi}{\tau}x\right)}{\sin\left(\frac{2\pi}{\tau}x\right)}\right\}$$

Equation (7) shows the fundamental wave torque and equations (8) and (9) show the pulsating torques with six-fold frequency. In the same way, there are τ_{11} and τ_{13} pulsating torques with 12-fold frequency. In other words, it is evident from this method that in thyristor motor with 6 pulses control, the largest component is generally the six-fold pulsating torque.

2) Squirrel cage induction motors

(1) Pulsating torque

In induction motors the field B_{R1} based on the rotor fundamental wave current arising by means of the fundamental wave excitation current in the stator winding current plays the same role as the field in equation (6). Therefore, since B_{R1} is proportional to the fundamental wave component of the primary current, the average torque when the thyristor converter is a power supply is the same value as for an ordinary motor with the same fundamental wave component and the harmonic current gives rise to the pulsating torque in the same way as described previously.

(2) Torque due to time harmonics

Since the 5th time harmonic field rotates in the opposite direction to the main field, the following negative torque arises:

$$\tau_5 = -\frac{k}{n_5} \cdot I'^{2}_{25} \frac{R'_{25}}{s_5} \quad \text{.................(10)}$$

where $s_5 = \frac{\nu+1-s_1}{\nu} = \frac{6-s_1}{5}$

I'_{25}: 5th harmonic current expressed in primary circuit

R'_{25}: resistance in respect to 5th harmonic expressed in primary circuit

n_5: 5th harmonic synchronous speed

k: constant

s_1: slip in respect to fundamental wave

The 7th time harmonic field rotates in the same direction as the main field so that a positive torque as show in equation (11) occurs:

$$\tau_7 = \frac{k}{n_7} \cdot I'^{2}_{27} \cdot \frac{R'_{27}}{s_7} \quad \text{.................(11)}$$

where $s_7 = \frac{\nu-1+s_1}{\nu} = \frac{6+s_1}{7}$

I'_{27}, n_6, R'_{27}: similar to that shown in equation (10)

During normal operation $s_1 = 1 \sim 0$, the loss descrived previously occurs but this torque is small and the effect on the fundamental wave torque is negligible.

III. IMPEDANCE

1. Commutating Reactance

When current is supplied to the 3-phase stator winding (considered as a rotating field type) of a synchronous motor by a thyristor converter, the rotating field, unlike with ordinary AC power supply connections, is equivalently produced by the sequential current flow between two phases. In this case, an impedance occurs in the motor when there is a change from one phase to another and the same commutation phenomenon occurs as in an ordinary rectifiers. This is investigated below qualitatively[4].

(1) Commutatorless shunt motors

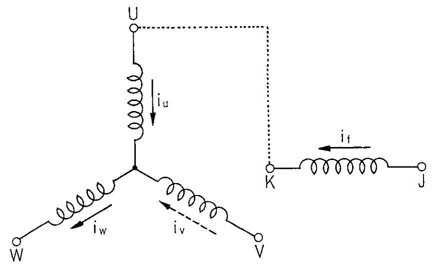


Fig. 5 Commutating current in windings (dotted line is for series winding)

The case to be considered is when there is commutation from a U-phase winding to a V-phase winding as shown in *Fig. 5.* With L_0 and L_S as the self inductance and leakage inductance of the stator winding and M as the mutual inductance between the field winding and the stator winding, the U-phase and V-phase voltage e_u and e_v are as shown in equations (12) and (13) respectively:

$$e_u = -(L_0+L_S)\frac{di_u}{dt} - L_0 \cos\frac{2\pi}{3} \cdot \frac{di_v}{dt} - \omega M i_f \cdot \sin \omega t \quad \text{.................(12)}$$

$$e_v = -(L_0+L_S)\frac{di_v}{dt} - L_0 \cos\frac{2\pi}{3} \cdot \frac{di_u}{dt} - \omega M i_f \cdot \sin\left(\omega t - \frac{2\pi}{3}\right) \quad \text{.................(13)}$$

During commutation, $e_u = e_v$ and when $L_S = \sigma L_0$, equation (14) is obtained:

$$\frac{d(i_v - i_u)}{dt} = \omega \frac{M}{L_0} \cdot i_f \cdot \frac{\cos\left(\omega t - \frac{\pi}{3}\right)}{\sin\frac{\pi}{3}\left(1 + \frac{\sigma}{2\sin^2\frac{\pi}{3}}\right)} \quad \text{.................(14)}$$

When integration is performed in the commutation period from $\frac{\pi}{2} + \frac{\pi}{3} - \gamma$ to $\frac{\pi}{2} + \frac{\pi}{3} - (\gamma - u)$, equation (15) is obtained, where γ is control angle of inverter:

$$\cos(\gamma - u) - \cos\gamma = \frac{2 i_u \cdot L_0}{i_f \cdot M} \cdot \sin\frac{\pi}{3}\left(1 + \frac{\sigma}{2\sin_2\frac{\pi}{3}}\right) \quad \text{.................(15)}$$

If $\omega i_f M = \sqrt{2}E$, $\omega \sigma L_0 = X_l$ (stator winding leakage reactance) and $\omega L_0 = X_0$, the above equation becomes equation (16):

$$\cos(\gamma - u) = \cos\gamma + \frac{i_u}{\sqrt{2}E\sin\frac{\pi}{3}}\left(X_l + \frac{3}{2}X_0\right) \quad \text{.................(16)}$$

Equation (16) is a general equation for shunt fields and is similar to that for ordinary rectifiers. Therefore, the commutating reactance X_u is equivalent to the $X_u = X_l + \frac{3}{2}X_0$ in the second term of

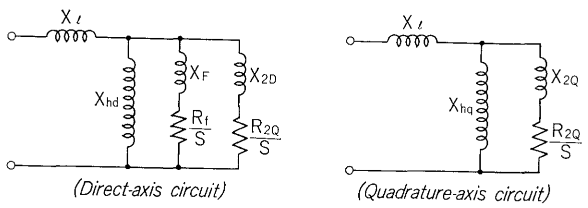


Fig. 6 Equivalent circuit of synchronous machine

the equation. X_l is caused by the stator winding leakage flux and X_0 is caused by the flux interlinking with the rotor circuit because of the armature reaction, but if there is no damper winding, this value becomes large. When there is a damper winding, this flux decreases directly corresponding to the leakage reactance drop in damper. In synchronous machines, the commutating reactance x_u (expressed as unit system) be determined as the reverse phase reactance x_2 which is the average of the subtransient reactances x_d'' and x_q'' of the d and q axes by analysis using the equivalent circuits of the d and q axes as shown in *Fig. 6*.

$$x_u = x_2 = \frac{x_d'' + x_q''}{2} \qquad \text{.................(17)}$$

It is evident that the overlapping angle u in equation (16) increases as the armature current i_u increases. From this, it is necessary in the thyristor motor that a strong damper winding is provided for reduction of the commutating reactance and the overlapping angle. The commutating reactance in the case of an induction motor can be considered as the sum of the primary leakage reactance x_1 and the secondary leakage reactance x_2, disregarding the exciting reactance.

(2) Commutatorless series motors

In the case of commutatorless series motors in which the field current i_f is proportional to the armature current, the connection is as shown by the dotted line in *Fig. 5* and when $i_f = ki_u$ in equation (15), equation (18) can be obtained:

$$\cos(\gamma - u) = \cos\gamma + \frac{L_0}{k \cdot M \cdot \sin\frac{\pi}{3}}\left(\sigma + \frac{3}{2}\right) \qquad \text{.........(18)}$$

Equation (18) shows that the overlapping angle u of the commutatorless series motor is not related to the armature current.

2. Internal angle δ and Impedance

In the thytistor motor of the motor commutation type, the firing angle of thyristor should be leaded with the control angle γ_0 in respect to the no-load induced voltage. In other words, it is always necessary to make leading current and assure the reactive current required for inverter operation.

Fig. 7 shows the vector diagram for the fundamental wave. As the load increases, the terminal voltage E_t decreases in respect to the no-load in-

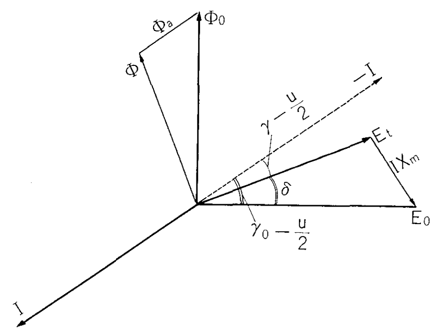


Fig. 7 Vector diagram of thyristor motor

duced voltage E_0 and the internal angle δ between E_0 and E_t perticular to synchronous motors increases. The value of δ can not be obtained from a simple equation and it is necessary to perform an analysis by the d and q axes method. When these results only are recorded, the equation becomes similar to that shown as equation (19).

$$\delta = \tan^{-1}\left\{\frac{\frac{\pi}{3} i(x_q - x_q'')\cos\left(\gamma_0 - \frac{u}{2}\right)}{e - \frac{\pi}{3} i(x_d - x_d'')\sin\left(\gamma_0 - \frac{u}{2}\right)}\right\} \qquad \text{.........(19)}$$

where e : motor voltage
x_d and x_q : synchronous reactance of d and q axes respectively

Equation (19) is similar to that for the ordinary synchronous motot but when the commutating allowable angle is δ_l, the following relation must be attained to ensure stable operation:

$$\gamma_0 - u - \delta \geqq \delta_l \qquad \text{.................(20)}$$

In other words, when γ_0 is constant, it is necessary that u and δ have sufficient margins in respet to the load current in commutatorless shunt motors. Therefore, it is desirable that the commutation reactance x_u be small so that overlapping angle u will be small and also that the synchronous reactances of x_d and x_q be small so that the internal angle δ will be small.

The leakage reactances x_1 and x_2 of induction motors are important to determine the maximum torque and when x_1 and x_2 are small, the possible operating range becomes wide, the commutating overlapping angle u is small and the condenser capacity for commutation can also be small.

IV. VARIOUS TYPES OF MOTORS

1. Ordinary Synchronous Motors and Squirrel Cage Induction Motors

Since the waveforms of the current and voltage applied by the thyristor inverter are rather distorted, many harmonic components are included. Therefore, the copper and iron losses are greater than with sinusoidal AC power supplies. The increases in iron loss are small and present not great problem but it is necessary to be sufficiently careful about increased copper losses in large capacity motors. Because round wires are used for stator windings in small capacity motors, the copper loss increase is small but in large capacity motors using square strand, effective methods to decrease the copper loss are making the strand thin and using transposed conductors. In addition, considering the increase in stray losses based on harmonic flux it is necessary to investigate the materials and dimensions of each part and to provide appropriate cooling.

For the pulsating torque based on the harmonic current, it is necessary to investigate the natural frequency and strength of various parts of the motor so that resonance will be avoided as much as possible and any resonance can be withstood.

Making the internal reactances x_d and x_2 as small as possible in synchronous motors makes the internal angle δ and the commutation overlapping angle u small and expands the operating range. The magnitude of x_d is determined by the stator winding leakage permeance and the gap length and that of x_2 by the leakage permeances of the field and damper windings. The cylindrical rotating field type is the most suitable since it has a very small leakage permeance of the field winding. When deciding the construction of each winding, the slot form, the form and length of coil end, etc. are to be selected so that the leakage permeance is a minimum, the gap length is to be larger than in ordinary synchronous motors and the armature reaction is to be small.

In squirrel cage induction motors, it is also economically desirable that the leakage reactance be small so that the condenser capacity for commutation of the converter can be small. In order to obtain good starting characteristics is ordinary squirrel cage induction motors, the operating characteristics are sacrificed somewhat and there are various constructions such as the double cage and the deep slot but since starting can be performed by frequency control, only the operating characteristics need be considered and the slot form and the coil end form should be selected so that the leakage permeance is a minimum. However, it is not advisable to make the gap length longer since the power factor of the motor deteriorate.

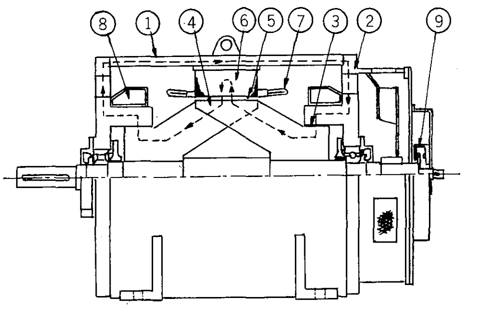
2. Synchronous Motors with Special Constructions

1) Permanent magnet type

This type is a rotating field type synchronous motor using a permanet magnet in the magnetic pole. Since the field strength is constant, the armature induced electromotive force is proportional to the rotating speed. A permanent magnet with large residual magnetism and large coersive force is used.

2) Reluctance type

When leading current flows in the armature of a synchronous motor, the armature reaction strengthens the magnetic field. Therefore, the field is excited even through there is no DC excitation so that the rotating field arises when multiphase AC current flows in the armature winding even though there is no excitation winding provided in the field. The reactive component of the current produces magnetic flux and rotation is caused by the interaction between this flux and the active component of the current. Since the rotor is of the salient pole type, the magnetic reluctance is changed in accordance with the relative positions of the armature and the field. A phase difference occurs between the current and magnetic flux. The relative positions of both change in respect to the load and there is rotation at a synchronous speed.



1. Frame
2. Bracket
3. Small gap between stator and rotor
4. Claw-pole
5. Main gap
6. Armature core
7. Armature winding
8. Excitation winding
9. Pole position senser

Fig. 8 Claw-pole type motor

3) Claw-pole type

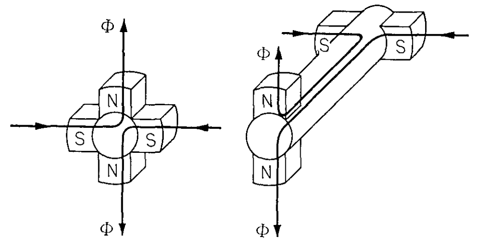
In this type, the rotor is of insertion type construction achieved by maintaining a gap on the left and right sides of the claw type massive iron core. As can be seen in *Fig. 8*, the field winding is arranged on the stator side and the magnetic flux circulates the circuit shown by the broken line, i.e. frame→bracket→small gap between stator and rotor →N polarity rotating pole→main gap→armature teeth→armature core→armature teeth→main gap→ S polarity rotating pole→small gap between stator and rotor→bracket→fram.

4) Unipolar type

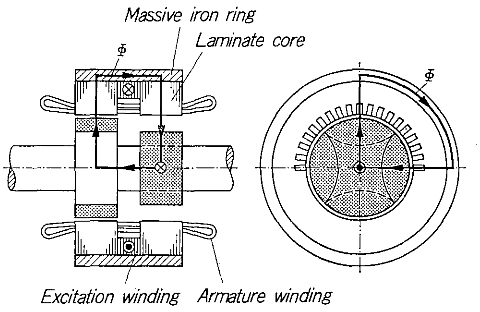
As can be seen in *Fig. 9*, magnetic poles of the same polarity are arranged mutually on the circumference of the rotor and a ring-type excitation winding is provided in the stator. The stator is constructed of two partial iron cores a common primary winding is inserted. Since the rotor is of simple shape, these motors are suitable as high speed machines.

3. Brushless Excitation

In thyristor motors, it is necessary to maintain excitation for operation over a wide speed control range from zero to maximum speed. When a synchronous generatc · of the rotating armature type



(a) Derivation of unipolar rotor from 4-pole salient rotor



(b) Construction

Fig. 9 Unipolar motor

is used as the exciter as in ordinary synchronous motors, excitation at zero speed is impossible. Therefore, a rotating transformer or a wound induction machine is used. When the wound induction machine is used at a slip of more than 1, the electrical output of the secondary winding is the sum of the input from the primary winding and the mechanical input from the shaft so that the capacity of the excitation source becomes small and so it is better than the rotating transformer.

Since the voltage induced in the secondary winding of the wound induction machine is proportional to the slip and the primary voltage, the secondary current, i.e. the field current changes in proportion to the slip when the primary winding is connected directly to a constant voltage source and the speed control become complex. In order to avoid this, a reactor and capacitor are connected on the primary side of the induction machine. The secondary current has no relation to the slip and is kept constant by means resonance including the excitation impedance. This is the constant excitation current circuit system developed originally by Fuji Electric.

V. CONCLUSION

Variable speed AC motors supplied from semiconductor power converters have become practical. The problems to be considered with various types of motors must be elucidated in detail in the future and the optimum values for both performance and cost will change particularly in accordance with the progress in semiconductor converters. Fuji Electric is continuing in its efforts to supply optimum products.

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